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# DROPLET SPRAYING DEVICE AND METHOD OF MANUFACTURING THE SPRAYING DEVICE

## Field of the Invention

**[0001]** The present invention relates to a liquid-drop spraying device placed in a raw material fuel discharging device which is used for a variety of machines for treating the above described liquid or for discharging a liquid raw material or fuel.

## Background of the Invention

**[0002]** A conventional liquid-drop spraying device is a liquid-drop spraying device performing spraying by discharging a liquid-drop from a discharging outlet due to the volume changes of a plurality of pressure chambers, which are connected to a common passage via inlets provided in these respective pressure chambers. A piezoelectric / electrostrictive element is formed on one portion of a wall in every pressure chamber and the relevant element is changed in shape by a voltage signal applied to the relevant element. Then, in the case where a large amount of a liquid is discharged by use of a raw material fuel discharging device, a large number of discharging units providing one piezoelectric / electrostrictive element in one pressure chamber are placed in a liquid-drop spraying device or the discharging period has been made shorter. In such a liquid-drop spraying device, for example, which is used as a fuel ejecting device densely arraying a large number of ejecting elements having a nozzle in a staggered arrangement on the entire inside wall surface of an inlet manifold in a carburetor of an internal combustion engine, there is a fuel ejecting device published in Japanese Unexamined Patent Publication No.

54-90416 (1979) official gazette. The cavity of each ejecting element is formed on the manifold wall so that the nozzle is located inside, and a piezoelectric vibrator is placed on the outside surface via a thin metal plate. Then, each ejecting element is connected to a fuel tank via passage equipped with a check valve, a liquid within a cavity is ejected from the nozzle towards the inside of a manifold by the vibration of the piezoelectric vibrator.

**[0003]** However, even if a liquid-drop spraying device is provided with a large number of discharging units in order to increase the discharging amount, since the displacement amount of the piezoelectric / electrostrictive element is small and the area where the discharging units are placed is limited, depending on the use, there have been cases where a sufficient discharging amount cannot be sprayed.

**[0004]** Moreover, manufacturing costs rise when a large number of discharging units are provided corresponding to the required discharging amount, and when a piezoelectric / electrostrictive element of small amount of displacement is integrally laminate molded with a pressure chamber to perform precise alignment on the pressure chamber.

**[0005]** Furthermore, even when the pressure chamber and piezoelectric / electrostrictive element are integrally sintered and formed as a means for suppressing the manufacturing cost, however, the material choices for the vibration source for increasing and reducing the pressure of a pressure chamber are limited.

**Summary of the Invention**

**[0006]** Accordingly, in order to solve the above described problems, the present invention provides a liquid-drop spraying device capable of spraying a liquid from a discharging outlet by a vibration source such as a piezoelectric / electrostrictive element is provided to a liquid sump with two or more pressure chambers and/or passages, and increases and reduces the pressure of the chambers in the liquid sump.

**[0007]** According to one embodiment of the present invention, a liquid-drop spraying device includes a liquid sump comprising a plurality of pressure chambers equipped with at least one discharging outlet, and a passage connected to one or more pressure chambers via an inlet for supplying a liquid, and a vibration source causing the liquid sump to change the volume, and in which at least two or more pressure chambers are provided with respect to the vibration source. Due to this, liquid can be discharged from a plurality of discharging outlets in one action by only driving one vibration source, the vibration source itself becomes larger, the selection of design can be varied more than conventional ones, and a larger displacement can be generated.

**[0008]** Now, the liquid sump is designed so that it does not have a valve structure in an inlet coupling a pressure chamber equipped with at least one discharging outlet and a passage supplying a liquid to one or more pressure chambers. When a liquid is discharged, since pressure variations caused by increasing and decreasing the pressure occur in pressure chambers, a large amount of back flow is not generated from the inlet provided in a narrow and small area to the passage. Moreover,

it is preferred that the vibration source is a member vibrating a predetermined vibration, and that the vibration source also includes a general vibration source, such as a solenoid coil and the like, beside the one in which an electric signal is converted directly to a physical operation such as a piezoelectric / electrostrictive element. Particularly, a piezoelectric / electrostrictive element provides an excellent (quick) response, a large force and high accuracy of vibrational amount, and it is preferable. Moreover, the structure of the piezoelectric / electrostrictive element is not limited to structures such as a single layer element having electrodes formed on both its sides. A composite element for enlarging special displacement in combination with other elastic materials and the like, and a laminated actuator including piezoelectric / electrostrictive elements and electrodes arranged over multilayers is suitable from the viewpoint of its low voltage driving ability and large displacement ability.

**[0009]** Moreover, according to another embodiment of the present invention, a liquid-drop spraying device is provided in which the liquid sump and the vibration source are separate bodies. Due to this, the vibration source can be individually formed separately from the liquid sump. For example, the vibration source can be formed from a material for enlarging the displacement amount, separately from the liquid sump. Moreover, if the material of the liquid sump is, for example, a metal, its toughness is enhanced, and its durability can be increased. And since the material components for forming the vibration source are not diffused to a side of a substrate equipped with the liquid sump, the

**[00010]** material of the substrate is stable and durability is further enhanced.

**[0010]** Now, as for the relationship between the vibration source and the liquid sump, while they do not need to contact each other in a constant state, it will be good if at least a vibrating portion or a movable portion is contacted for the transition of vibration even if they are apart during a certain interval. However, in the case where the vibration is transmitted to a plurality of pressure chambers at the same time by the same vibration source, it is preferred that the vibration source and liquid sump contact each other even in a constant state. Concretely, they are retained in a contacted state by a mechanical adjustment means such as a spring, a screw and the like. Moreover, the liquid sump and the vibration source which are separate bodies can be also fixed by an adhesive, a filler added adhesive, a thermal diffusion method and the like. Furthermore, the movable section of the vibration source is not necessarily required to be directly neighboring to or in contact with the liquid sump, and it is sufficient to contact the vibration source via at least one relaying member for transmitting vibrations to the liquid sump. In this case, since adjustment can be carried out by the relaying member, alignment of the vibration source becomes unnecessary, reducing the number of the vibration sources becomes possible, and cost reduction is contemplated.

**[0011]** Moreover, according to the present invention, a liquid-drop spraying device is provided in which one portion of the vibration source is fixed on a fixation section such as a base frame or the like, and at least one portion of other vibration portions or movable

portions contact the liquid sump. Due to this, the vibration of the vibration source is more efficiently transmitted to the liquid sump, and spraying efficiency is enhanced.

**[0012]** Moreover, according to the present invention, a liquid-drop spraying device is provided in which at least one of the contact surfaces between the vibration source and the pressure chambers is in a convex shape. Now, the contact surface is referred to as a vibration transmitting surface for the vibration source and the vibration transmitted surface for the pressure chamber to cause volume change in the pressure chamber by the vibration source, and in the case where at least one of them is in an outwardly convex shape, the other can have any of a convex shape, a smooth shape and a concave shape in a constant state, provided that vibrations can be transmitted.

**[0013]** Moreover, according to the present invention, a liquid-drop spraying device is provided in which the vibration transmitting surface of the vibration source is smooth, and the vibration transmitted surface of the pressure chamber is a thin walled portion projecting outwardly. It is preferred that the pressure chamber includes a thin walled portion projecting outwardly, which is formed at the same time when the liquid sump including the pressure chamber is formed, and it is also preferred that a projecting object is formed by adhesion or the like at a predetermined location on the vibration transmitted surface after forming the liquid sump.

**[0014]** Moreover, according to the present invention, a liquid-drop spraying device is provided in which at least one of the contact surfaces where the vibration source and the passage contact each other is in a

convex shape. Due to this, the change in the volume due to the increasing and reducing pressures in the passage caused by the vibration source disperses to a plurality of volume reduction sections via the inlet and causes a droplet to discharge.

**[0015]** Now, although the shape of the pressure section of the vibration source is appropriately defined by the shape of the passage, it is not necessarily limited to a shape for pressurizing the entire passage area. Concretely, it is preferable that only a center portion of the thin walled section located above the passage is contacted, and in the case where a plurality of passages exist, it is also preferable that all of the passages are pressurized. It is also preferable that only a portion of the partial passage is pressurized considering the distance from the inlet and it is selected according to the discharging efficiency, dimensions, shape and the like.

**[0016]** Moreover, according to the present invention, a liquid-drop spraying device is provided including bridge portions between the pressure chambers that contact the vibration source. Now, it is preferable that in the case where at least one of the contact surfaces is in an outwardly convex shape, the other has any one of a convex shape, a smooth shape and a concave shape. Particularly, in the case where a thin walled portion of a pressure chamber is formed in a concave shape with respect to the bridge portion, when the flat vibration source pressures the bridge portion once, the bridge portion shifts to the pressure direction and the central portion shifts to the opposite of the pressure direction with respect to an end portion of thin walled portion in a concave shape, and then the volume of the pressure chamber increases and the liquid is supplied

from the passage. And, as the pressuring of the vibration source is completed, the pressure chamber returns to the original state and when the volume decreases, the liquid is discharged from the outlet, and by repeating this, the liquid is sprayed. Due to this, the bridging portion has a thickness in the direction of the increasing and reducing pressure of the vibration plate that is greater compared to the thin walled portion, therefore, the bridging portion exhibits much better durability than the thin walled portion.

**[0017]** Besides this, forming the thin walled portion in a concave shape indicates that if it is in a convex shape, a step of making the height of the convex be certain level is required, while the height of the bridge portion is the same with the thickness of the entire device. Therefore, it is easy to make a substrate with the thin walled portion in a convex shape and the number of steps is reduced. It should be noted that when the bridging portion is pressured by the vibration source and an end portion of the thin walled portion in a concave shape shifts in the direction of pressuring, the bottom portion with respect to the thin walled portion of the pressure chamber requires a thickness that is not shifted, and the amount of thickness needed can be appropriately adjusted by material selection, mixing rate, and the length, width and thickness of the bridging portion. Moreover, by adjusting the dimensions, shapes and the like of the pressure chamber and the bridge portion, it can be also designed so that the volume capacity of the pressure chamber is reduced when pressuring. For example, in the case where the width of the bridge portion is sufficiently narrowed with respect to the

pressure chamber, or in the case where the side face of the pressure chamber is formed diagonally with respect to the upper surface or the bottom surface, the upper surface and the bottom surface are deformed in parallel so that the total thickness of the entire device is reduced, thereby reducing the volume and the like of the pressure chamber to discharge the liquid.

**[0018]** Moreover, according to the present invention, a method of manufacturing a liquid-drop spraying device is provided, in which after a liquid sump consisting of a plurality of pressure chambers having at least one discharging outlet and a passage connected to one or more pressure chambers via an inlet for supplying a liquid is separately formed from the vibration source for causing the liquid sump to change volume, the liquid sump and the vibration source are integrated so that the vibrations of the vibration source are transmitted to the liquid sump, such that two or more pressure chambers are provided with respect to the vibration source. Due to this, since the vibration source and the liquid sump can be formed by different materials and steps, for example, the vibration source can formed from a material for enlarging the amount of displacement which is different from the material of the liquid sump which has been sintered, and the material of the liquid sump can be a metal having a high toughness and durability. Then, since the material component forming the vibration source does not diffuse to the liquid sump substrate, the material of the substrate becomes stable and its durability can be more enhanced, and furthermore, the liquid sump and the vibration source can be individually checked, and better reliability is secured.

**Brief Description of the Drawings**

**[0019]** FIG. 1 is a vertical sectional view of a discharging unit of a liquid-drop spraying device;

FIGS. 2(a)-2(c) are illustrations showing another liquid-drop spraying device;

FIG. 3 is an illustration showing another liquid-drop spraying device;

FIG. 4 is a perspective view showing the liquid-drop spraying device of FIG. 3; and

FIGS. 5(a) and 5(b) are illustrations showing another liquid-drop spraying device.

**[0020]** Description of the reference numerals used in the Figures:

1 DISCHARGING UNIT OF THE LIQUID-DROP SPRAYING DEVICE;
10 PRESSURE CHAMBER;
10a THIN WALLED PORTION;
11 DISCHARGING OUTLET;
11a NOZZLE HOLE;
12 INLET HOLE;
13 VIBRATION SOURCE;
13a PIEZOELECTRIC/ELECTROSTRICTIVE ELEMENT;
13b ACTUATOR;
14 BRIDGING PORTION;
15 ELECTRODE; and
20 PASSAGE.

**Detailed Description of the Invention**

**[0021]** The modes for carrying out a liquid-drop spraying device according to the present invention will be described in detail below.

**[0022]** FIG. 1 is a vertical sectional view of a discharging unit 1 of a liquid-drop spraying device.

The pressure chamber 10 discharges a liquid-drop due to a reduction in the volume of the liquid sump and includes a discharging outlet 11 having a nozzle hole 11a which opens outwardly in a lower portion of an end thereof, an inlet 12 on the other end of the surface on which discharging outlet 11 is provided, and the pressure chamber 10 is connected to the passage 20 via the inlet 12. Moreover, on an upper wall portion of the pressure chamber 10, the vibration source 13 is integrally provided and mounted in a transverse direction so as to range over the upper wall portions of other pressure chambers 10 transversely arranged in parallel. The vibration source 13 is the piezoelectric / electrostrictive element 13a, which includes an upper portion electrode, the piezoelectric / electrostrictive layer and the lower portion electrode, which are laminated together. By applying a predetermined voltage signal to the piezoelectric / electrostrictive element, the piezoelectric / electrostrictive element is deformed by the electric field generated between the upper portion electrode and the lower portion electrode, which deforms the wall portions of multiple pressure chambers 10 at the same time.

**[0023]** Thus, liquid supplied to the respective pressure chambers 10 is discharged as liquid-drops from the discharging outlet 11 at the same time by the pressurized force generated in the respective pressure chambers 10. As the lower surface of the vibration source 13 rises upward to return to the original position, the thin walled portions 10a of the multiple pressure chambers 10 also return to the original shape at the same time, and liquid is supplied via the inlet 12 to a respective pressure chamber 10 from the passage 20 due to a negative force generated in the respective

pressure chambers 10 as the device prepares for the next ejection. Liquid drops are ejected (sprayed) by repeating this process.

**[0024]** FIG. 2(a) is an illustration showing another embodiment of the liquid drop spraying device according to the present invention. The pressure chambers 10 includes discharging outlets 11 having nozzle holes 11a, which open outwardly in a lower portion of an end thereof, includes inlets 12 on the other end of the surface on which the discharging outlets 11 are provided, and the respective pressure chambers 10 are connected to the passage 20 via the inlets 12. Particularly, the thin walled portions 10a of the pressure chambers 10 are formed outwardly in a convex shape, and a concave portion is formed between this and the thin walled portion 10a of another laterally located pressure chamber 10.

**[0025]** On the other hand, a separately formed vibration source 13 is provided in an upper position of the upper wall portion of the pressure chamber 10. The lower surface of the vibration source 13 is formed smoothly (e.g., flat), in a usual state, and the lower surface of the vibration source 13 and the thin walled portions 10a of the pressure chambers 10 contact each other. Moreover, the vibration source 13 is also formed in a longitudinal shape in a transverse direction so as to range over the upper wall portion of the other pressure chambers 10 arrayed laterally in parallel.

**[0026]** The vibration source 13 is an actuator 13b formed by laminating piezoelectric / electrostrictive elements and electrodes over a plurality of layers, and provides excellent low voltage driving ability and high displacement ability as a structure vibrating upwardly

and downwardly. By applying a predetermined voltage signal to the actuator 13b, the lower surface of the vibration source 13 at the illustrated position is lowered, and liquid supplied to the respective pressure chambers 10 is discharged as liquid-drops at the same time from the discharging outlets 11 due to the pressurized force generated in the respective pressure chambers 10 by simultaneously deforming the thin walled portions 10a in a convex shape outwardly from the multiple pressure chambers 10. As the lower surface of the vibration source 13 rises upward to return to the original position, the thin walled portions 10a of the multiple pressure chambers 10 also return to their original shapes at the same time, and liquid is supplied via the inlet 12 to the respective pressure chambers 10 from the passage 20 due to a negative force generated in the respective pressure chambers 10 as the device prepares for the next ejection. Liquid drops are ejected (sprayed) by repeating this process.

**[0027]** FIGS. 2(b) and 2(c) show forms of laminated actuators 13b utilizing a longitudinal piezoelectric effect and a transverse piezoelectric effect, respectively, which are selected according to the required drive voltage, the amount of displacement, the desired shape and the like.

**[0028]** FIG. 3 and FIG. 4 are illustrations showing other embodiments of the liquid drop spraying device according to the present invention. Although the pressure chambers 10 include discharging outlets 11 having the nozzle holes 11a, which open outwardly in a lower portion of a respective end thereof, since in this embodiment the pressure chambers include inlets 12 on an upper surface of the other end of the surface on which the discharging outlets 11 are provided and the

pressure chambers are connected to the passage 20 via the inlets 12, the passage 20 is located in an upper position compared to that of the pressure chamber 10, in a positional relationship closer to the upper surface of the discharging unit 1.

**[0029]** On the other hand, above the upper wall portion of the pressure chambers 10, the vibration source 13 is separately formed and fixed partially on a base frame, the lower surface of which is the movable section of the vibration source 13, and the thin walled portions 10a are formed in a smoothed manner.

**[0030]** FIG. 4 is a perspective view showing the positional relationship between the vibration source 13 and the passage 20. A pair of pressure chambers 10, 10 shown in FIG. 3 are transversely arrayed in parallel, above which the vibration source 13 is located and formed in a longitudinal shape along the longitudinal direction of the passage 20 connecting the multiple pressure chambers 10.

**[0031]** The vibration source 13 has also a structure for vibrating upwardly and downwardly as the actuator 13b, by applying a predetermined voltage signal, the position shown in FIG. 4 of the lower surface of the vibration source 13 is lowered with respect to the base frame on which it is mounted, causing the passage 20 to deform, the supplied liquid is discharged from the discharging outlet 11 of the respective pressure chamber 10 as liquid-drops at the same time by conveying the liquid to the respective pressure chambers 10 simultaneously due to the pressurized force generated in the passage 20. As the lower surface of the vibration source 13 rises upwardly to return to the original position, the passage 20 also returns to original shape and liquid is supplied to the passage 20

due to a negative force as the device prepares for the next ejection. Liquid drops are ejected in a spraying manner by repeating this.

**[0032]** FIG. 5 is also an illustration showing another embodiment according to the present invention. The pressure chambers 10 include discharging outlets 11 having nozzle holes 11a that open outwardly in a lower portion of an end thereof, inlets 12 on the other end of the surface on which the discharging outlets 11 are provided, and the respective pressure chambers 10 are connected to the passage 20 via the inlet 12. Particularly, the thin walled portions 10a of the pressure chambers 10 are formed in a convex shape inwardly, and the bridging portion located between this and the thin walled portion 10a of an adjacent pressure chamber 10 (located laterally) is formed projecting outwardly. Then, over the upper wall portion of the pressure chambers 10, the vibration source 13 is provided, which is separately formed with its lower surface in a smoothed manner. FIG. 5 (a) shows the state when contact between the lower surface and the upper surface 14a of the bridging portion 14 is kept. Moreover, the vibration source 13 is also formed in a longitudinal shape in a transverse direction so as to range over the upper wall portion of the other pressure chambers 10 transversely arrayed in parallel.

**[0033]** The vibration source 13 also has a structure for vibrating upwardly and downwardly as the actuator 13b. By applying a predetermined voltage signal, the lower surface of the vibration source 13 is lowered to the position shown in FIG. 5(b), the bridging portion 14 between the multiple pressure chambers 10 is deformed downwardly at the same time, and liquid is supplied from the passage 20 to the respective pressure

chambers 10 due to the negative force generated by the respective pressure chambers 10 being rectangularly deformed. As the lower surface of the vibration source 13 rises upwardly to return to the original position, the bridging portion 14 also simultaneously returns to the original shape and liquid supplied to the respective pressure chambers 10 is discharged from the discharging outlets 11 as liquid-drops at the same time, due to the pressurized force generated in the respective pressure chambers 10. Liquid-drops are ejected in a spraying manner by repeating this.

**Industrial Applications**

**[0034]** As described above, according to the present invention, since at least two pressure chambers are connected to at least one discharging outlet and are provided with respect to a single vibration source of a liquid-drop spraying device, en bloc discharging from a plurality of discharging outlets can be performed by driving a single vibration source, and the width of the design can be broadened compared to the conventional ones. This can generate a larger displacement since the vibration source itself is larger and uses other kinds of materials, thereby resulting in an increased spraying capacity.

**[0035]** Moreover, according to another embodiment of the present invention, a liquid-drop spraying device in which the liquid sump and the vibration source are separate bodies is provided. Due to this, in addition to the above described effects, the vibration source and the liquid sump can be separately formed, for example, the vibration source is capable of being formed from materials which enable enlarged displacement separately from the liquid sump.

Moreover, in the case where materials for the liquid sump are defined as, for example, a metal, the toughness is enhanced and the durability can be enhanced. Then, since the material components for forming the vibration source do not diffuse to the side of the substrate housing the liquid sump, the material of the substrate is stable and the durability is enhanced.

**[0036]** Moreover, a liquid-drop spraying device is provided in which one of the portions of the vibration source is fixed on a fixation section of the base frame and the like, at least one of the portions of the other vibration section or movable section contacts the liquid sump. Due to this, the vibrations from the vibration source do not transmit to the fixation portion side, and vibrations are more efficiently transmitted to the liquid sump such that the spraying efficiency is enhanced.

**[0037]** Moreover, a liquid-drop spraying device is provided in which the vibration source and the pressure chamber contact each other, and at least one of the contacted surfaces is in a convex shape. Since many kinds of shapes can be used for the surfaces, the shape can be selected corresponding to the materials of the liquid sump and the vibration source, the discharging amount or the like, and to provide stable discharging.

**[0038]** Moreover, a liquid-drop spraying device is provided in which the vibration transmission surface of the vibration source is smoothed, and the vibration submitted transmission surface of the pressure chamber is a thin walled portion projecting outwardly. Since the pressure chamber having a thin walled portion projecting outwardly can be easily prepared using conventionally integrated projecting unit forming

methods, the cost of preparation can be reduced.

**[0039]** Moreover, a liquid-drop spraying device is provided in which the vibration source and the passage contact each other, and at least one of the contacted surfaces is in a convex shape. Due to this, the volume change due to the increasing and reducing pressures applied to the passage from the vibration source are dispersed into a plurality of volume reduction sections via an inlet, and discharging of the liquid-drop is performed. It is not necessary to individually mount a large number of vibration sources as the conventionally known, and the cost of preparation can be reduced.

**[0040]** Moreover, a liquid-drop spraying device is provided in which a bridging portion between the pressure chambers contacts the vibration source. Due to this, the bridging portion has a larger thickness than that of the thin walled portions with respect to the direction of increasing and reducing pressures of the vibration plate and is excellent in durability. In addition, forming the thin walled portion in a concave shape, as compared to the case where it is formed in a convex shape and requires a step of adjusting the height of the convex shape to be a certain level, it is easy to make the substrate and the number of steps are also reduced, since the height of the bridging portion is the same as the thickness of the entire device.

**[0041]** Moreover, a method of manufacturing a liquid-drop spraying device is provided in which, after a liquid sump and the vibration source are separately formed, two or more respective pressure chambers are provided with respect to the vibration source by integrating the liquid sump and the vibration source so that vibrations from the vibration source are transmitted to the liquid sump. Due to this, since the vibration source and the liquid sump can be formed by

different materials and steps, for example, the vibration source can be formed by a material for enlarging the displacement amount and separately from the conventional sintering materials of liquid sumps, and the material of the liquid sump can be a metal having a high toughness and durability. Then, since the material component forming the vibration source does not diffuse to the side of the substrate having a liquid sump by reduction of contact area, the material of the substrate becomes stable and its durability can be more enhanced, and furthermore, the liquid sump and the vibration source can be individually checked, and reliability is further secured.